The Kaya Identity: Energy Use, Conservation and Efficiency

EES 3310/5310

Global Climate Change

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Class #24: Friday, March 19 2021

Myth 3:
We have all
the technology we need.

Do we have the technology?

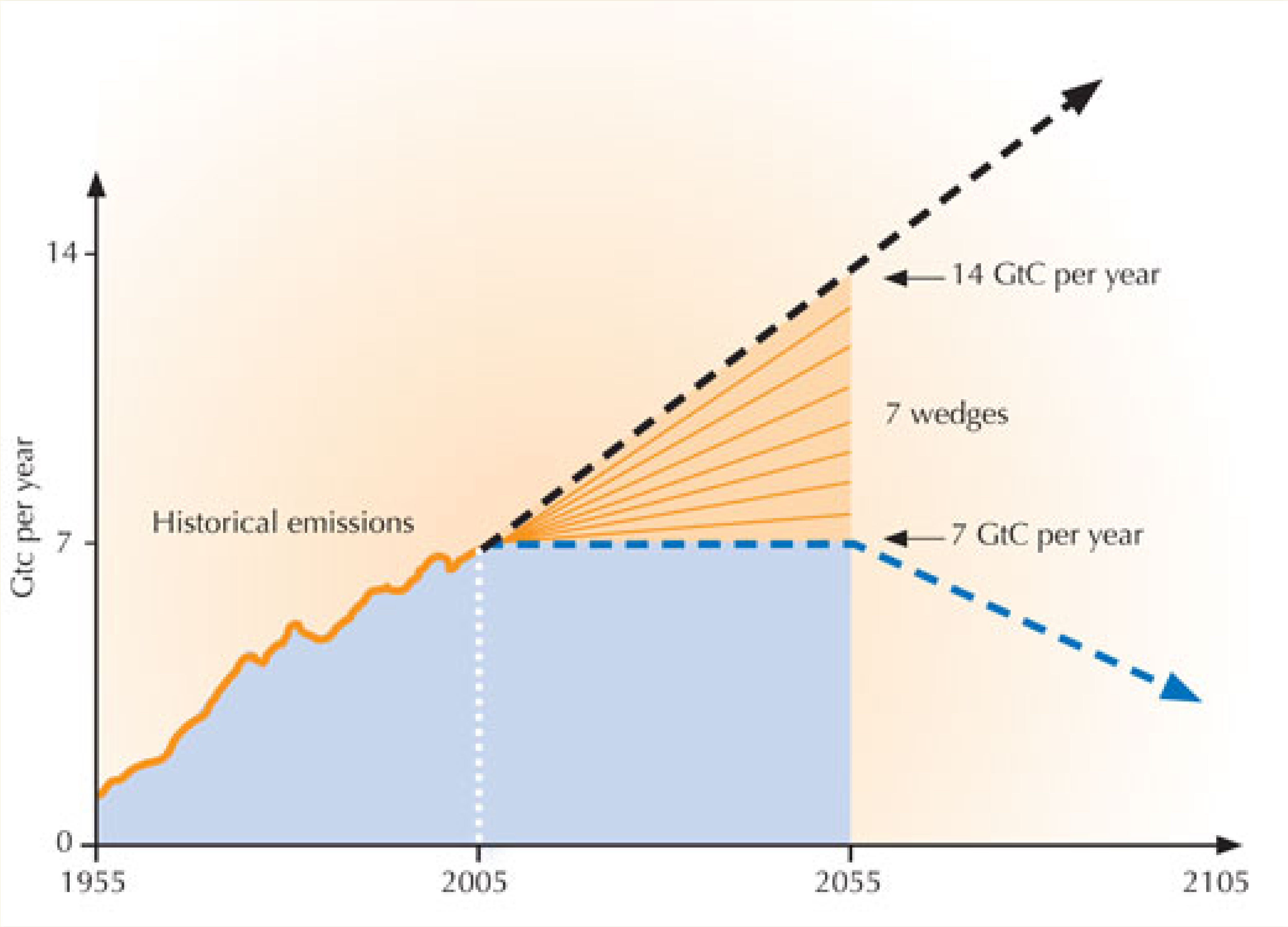
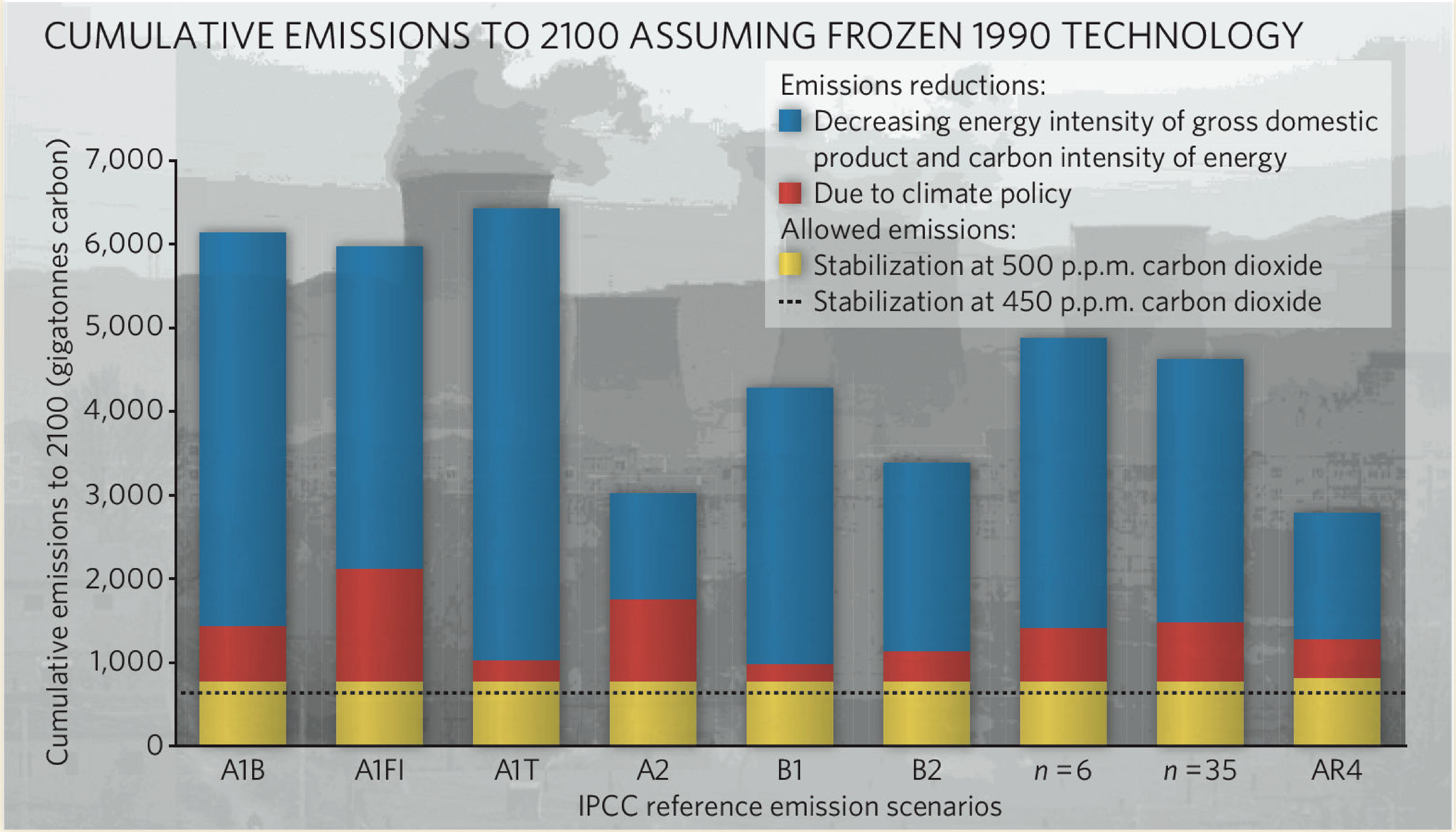


Image credit: S. Pacala & R. Socolow, *Science* **305**, 968 (2004). doi: 10.1126/science.1100103

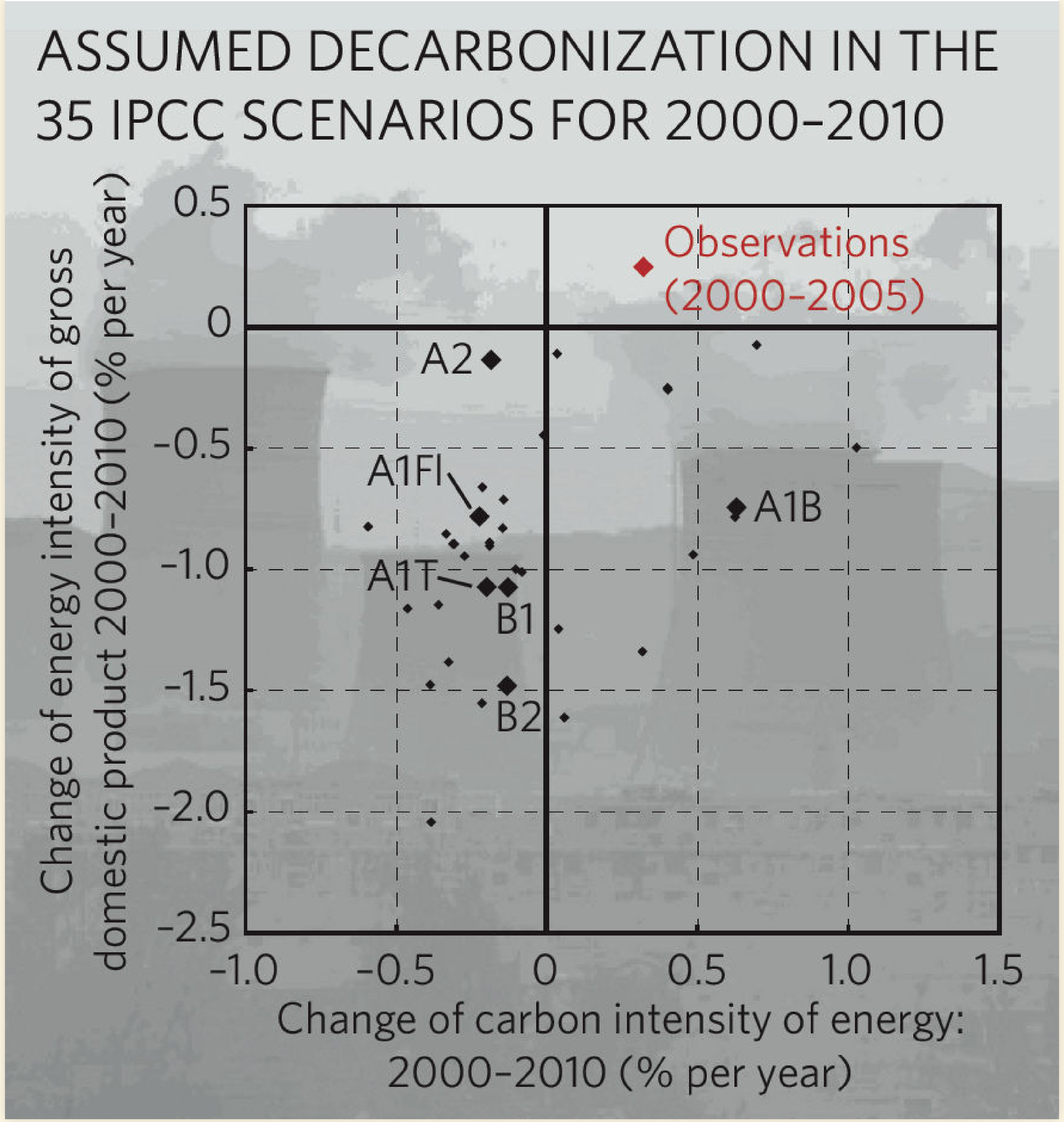
Do we have the technology?



R.A. Pielke, Jr. et al., Nature **452**, 531 (2008). doi: 10.1038/452531a

- Blue = Assumed spontaneous emissions reduction
- Brown = Regulations
- Yellow = Allowed emissions to stabilize CO_2 at 550 ppm.

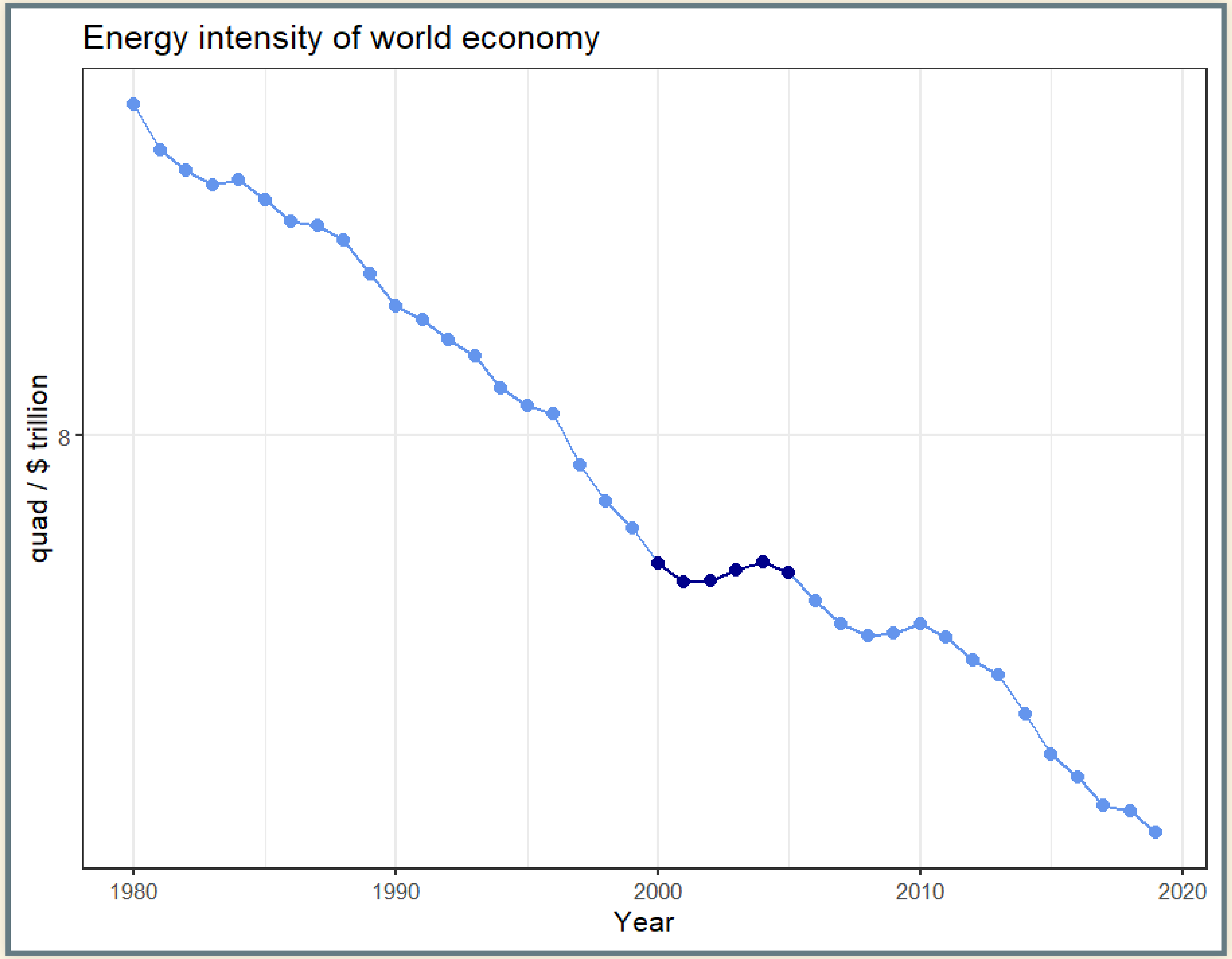
Optimism on energy efficiency

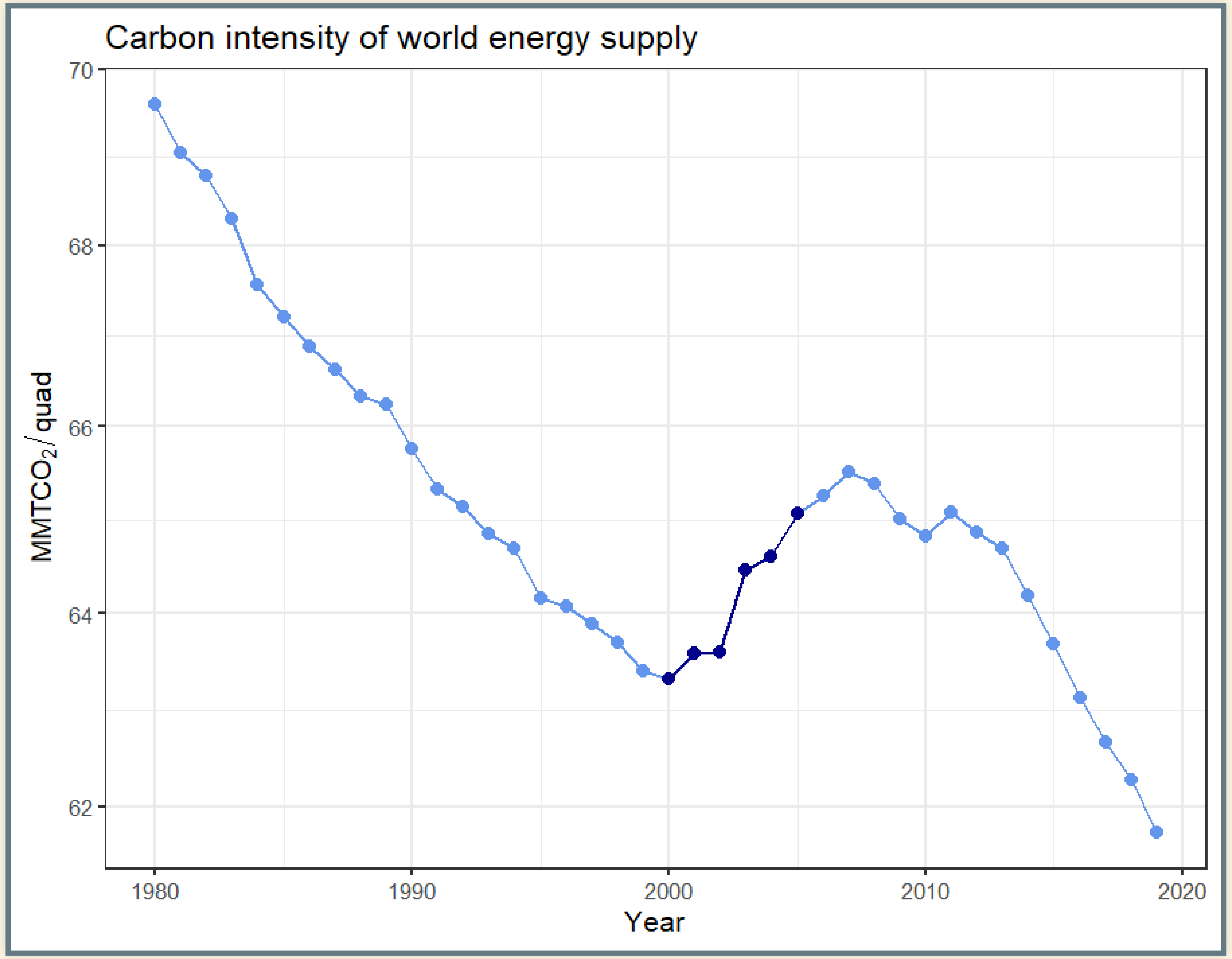


R.A. Pielke, Jr. et al., Nature **452**, 531 (2008). doi: 10.1038/452531a

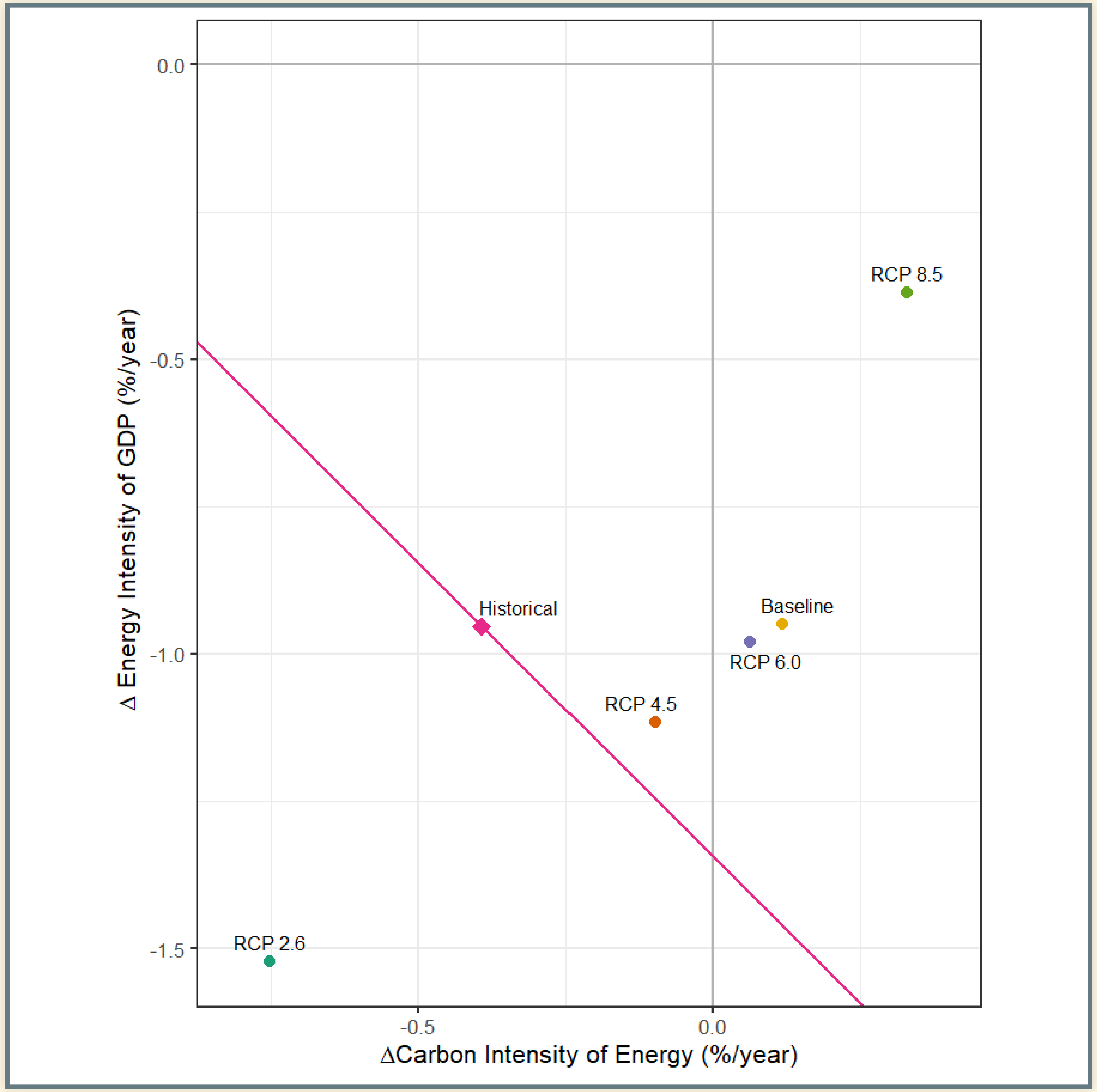
The View from 2018:

- Pielke's numbers focus on 2000–2005
  - The years when China's economy began really rapid growth
- After 2005, things changed:





Current Emissions Pathways



- Comparing actual trends for 2005–2017 to trends for 2005–2020 in 5 emissions scenarios:
  - Points above & right of the magenta line have higher emission trends than historical
  - Points below & left of the magenta line have lower emission trends than historical
- The historical trend from 2005–2017 is doing better (lower emissions) than several scenarios including baseline (no policies) and RCP 6.0 (business as usual with current policies).

Summary

- Pielke and others were very pessimistic around 2010
- Ten years later:
  - Some reasons for greater optimism
  - But still cause for concern

2021 UN Report

Sections

The Washington Post

Democracy Dies in Darkness

Climate and Environment

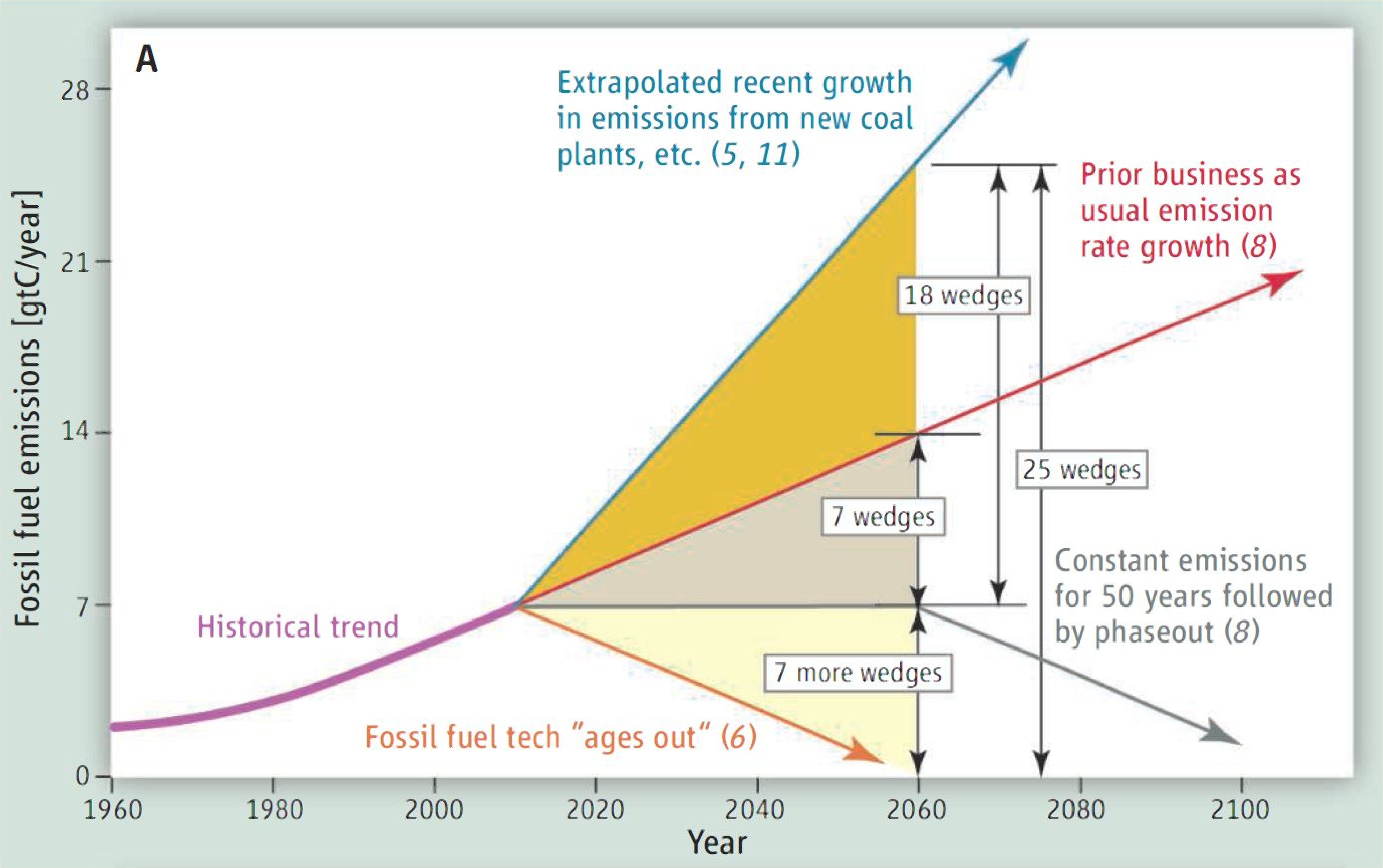
United Nations: Countries' pledges to cut emissions are far too meager to halt climate change

New analysis shows the world remains on a perilous trajectory, even as global leaders have promised more urgent action.

"Current levels of climate ambition are very far from putting us on a pathway that will meet our Paris agreement goals," said Patricia Espinosa, executive secretary of the U.N. Framework Convention on Climate Change.

Even if countries follow through, [they] would put the world on a path to achieve only a 1 percent reduction in global emissions by 2030….
By contrast, scientists have said that emissions must fall by nearly 50 percent this decade for the world to realistically have a shot at avoiding devastating temperature rise.

Do we have the technology?



M.I. Hoffert, *Science* **329**, 1292 (2010) doi: 10.1126/science.1195449

Decarbonizing Global Economy

Decarbonizing Global Economy

- World needs lots more energy
  - National/industrial energy poverty:
    - Energy consumption for economic growth
  - Household energy poverty:
    - Energy consumption for quality of life

Energy

Image credit: NASA

Population Density

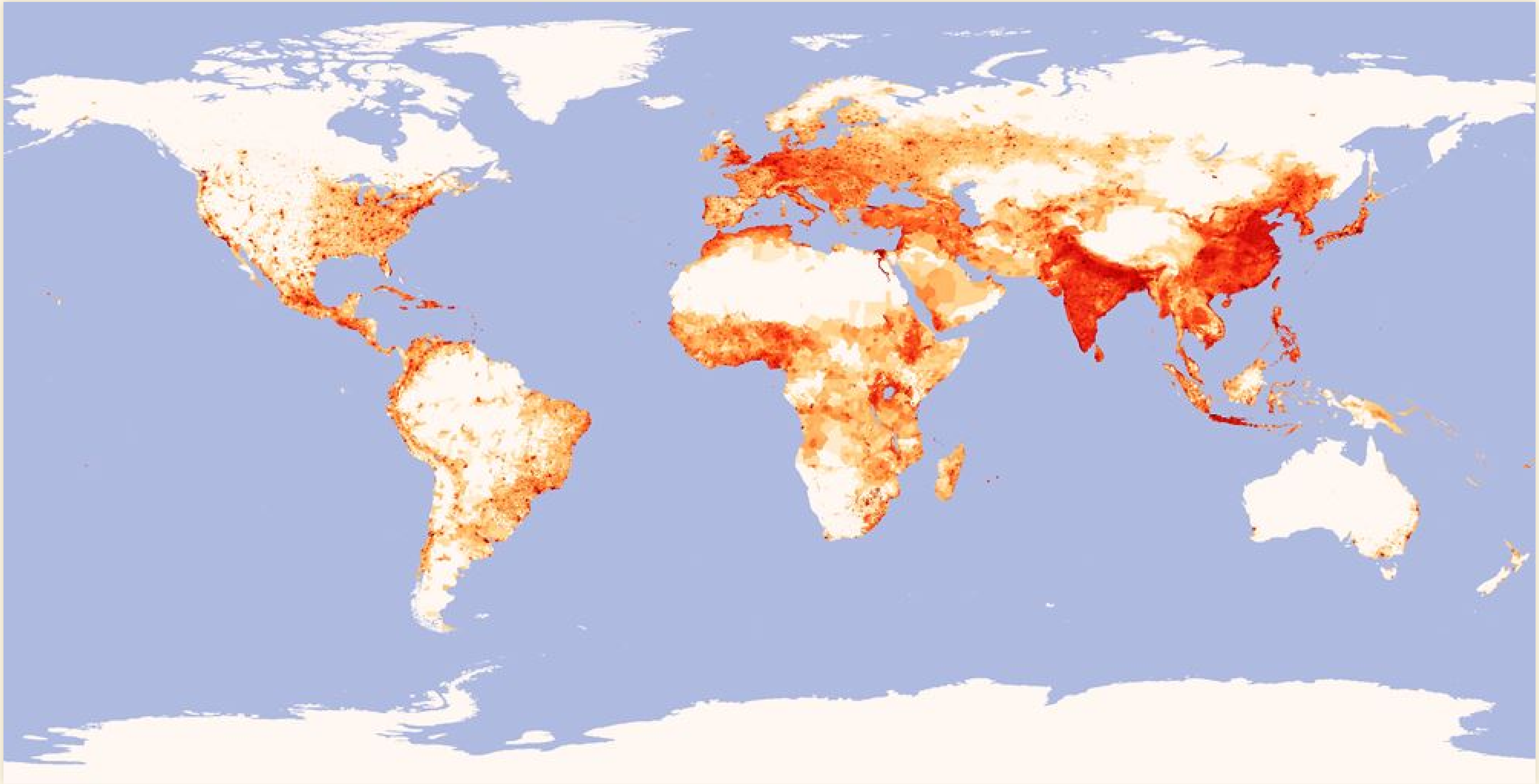


Image credit: NASA

Energy Poverty

Photo: Rebecca Blackwell, Associated Press, June 2007.

Household Energy Poverty

- Roughly 1.2 billion people do not have acccess to electricity.
  - Down from 1.5 billion in 2008
- Benefits of providing even a little electricity:
  - Children study 30% more with just one light bulb in home.
  - Women have more say in household decisions
  - Allows economically productive activity in evening
- Role of refrigeration in preventing disease
- Electricity and gas reduce exposure to indoor air pollution
  - Indoor air pollution from cooking, lighting kills around 4.3 million/year
- Home solar typically provides light, but insufficient for refrigeration, cooking

Measuring Energy and Environmental Impact

Measuring Energy

- Heat:
  - BTU (British Thermal Unit) = quantity of heat
  - Quad = quadrillion BTU
  - Kilowatt Hour (kWh): measure of electricity
- Conversions:
  - 1 quad is about 300 billion kWh
  - 1 quad per year is about 11 billion watts
    - Typical large power plant (coal or nuclear) produces an average of around 750 million watts
    - 1 quad per year is about 15 big power plants
- Magnitudes
  - World uses about 550 quads per year of primary energy
  - U.S. uses about 90 quads per year of primary energy
    - 4% of population, 16% of energy consumption

Some Definitions:

- Primary vs. Secondary
  - Primary energy consumption = heat generated
  - Secondary energy consumption = useful energy consumed
    - Coal generation is about 33% efficient
    - Gas generation is about 45% efficient
    - A car engine is about 33% efficient
  - More efficient generation can produce more secondary energy with less primary energy.
- Nameplate vs. Average Power Output:
  - Nameplate = power when operating at 100% capacity
  - Capacity factor = average fraction of maximum capacity achieved over a year
  - Actual energy produced = nameplate power × capacity factor × 1 year

Kaya Identity

Kaya Identity

$$F = P \times g \times e \times f$$

- F = emissions (million tonnes carbon per year)
- P = population (billions)
- g = per-capita GDP ($1000 per person)
- e = energy intensity of economy (quads / trillion dollars)
- f = carbon intensity of energy supply (million tonnes carbon / quad)

Policy

- We can't directly control P
- We want g to grow
- Therefore, decrease e and f

Economic and Energy Trends

Interactive Tool

https://ees3310.jgilligan.org/decarbonization/

Kaya data and analysis for your own computer:

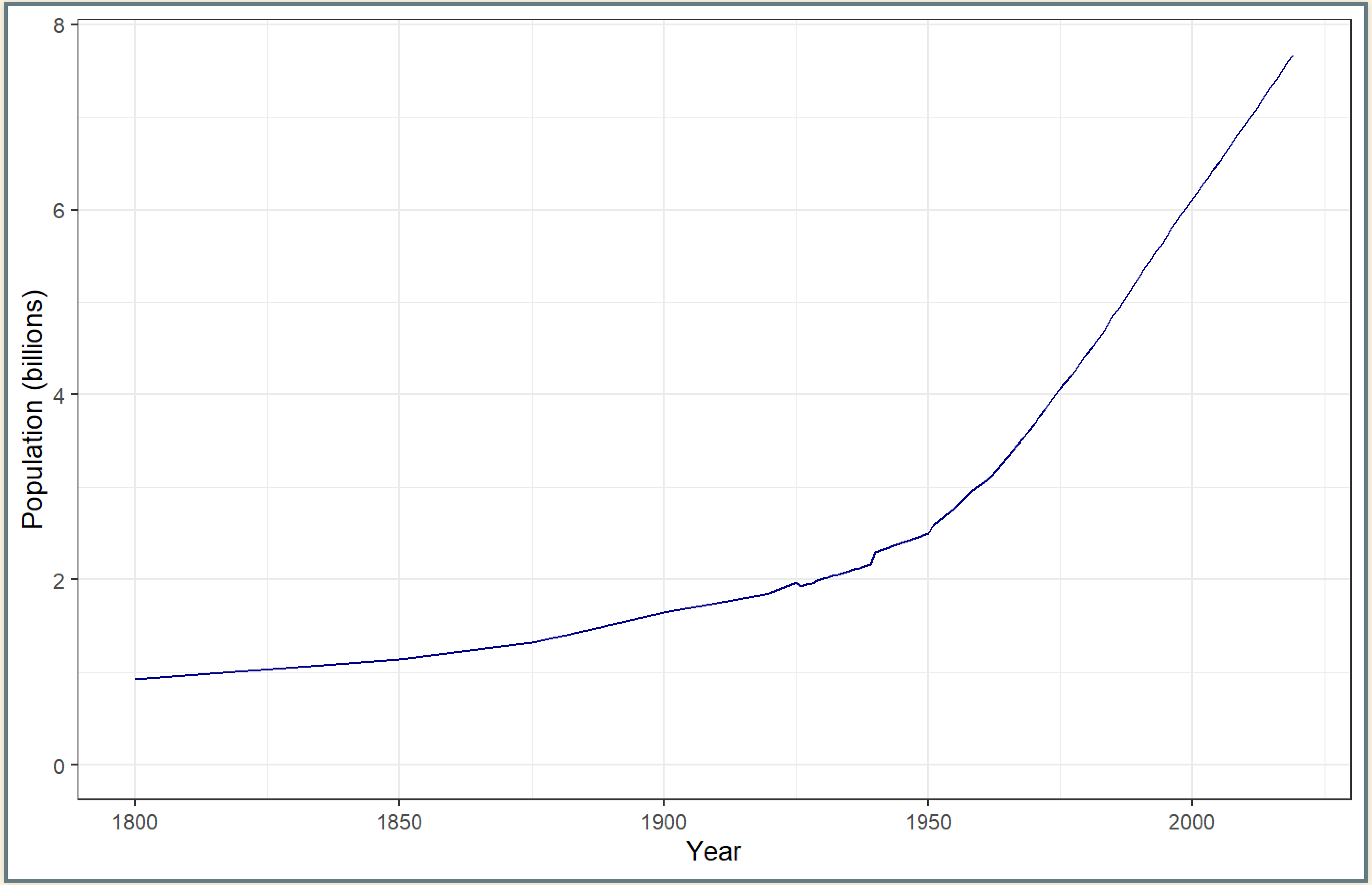
https://jonathan-g.github.io.kayadata

```
install.packages("kayadata")
```

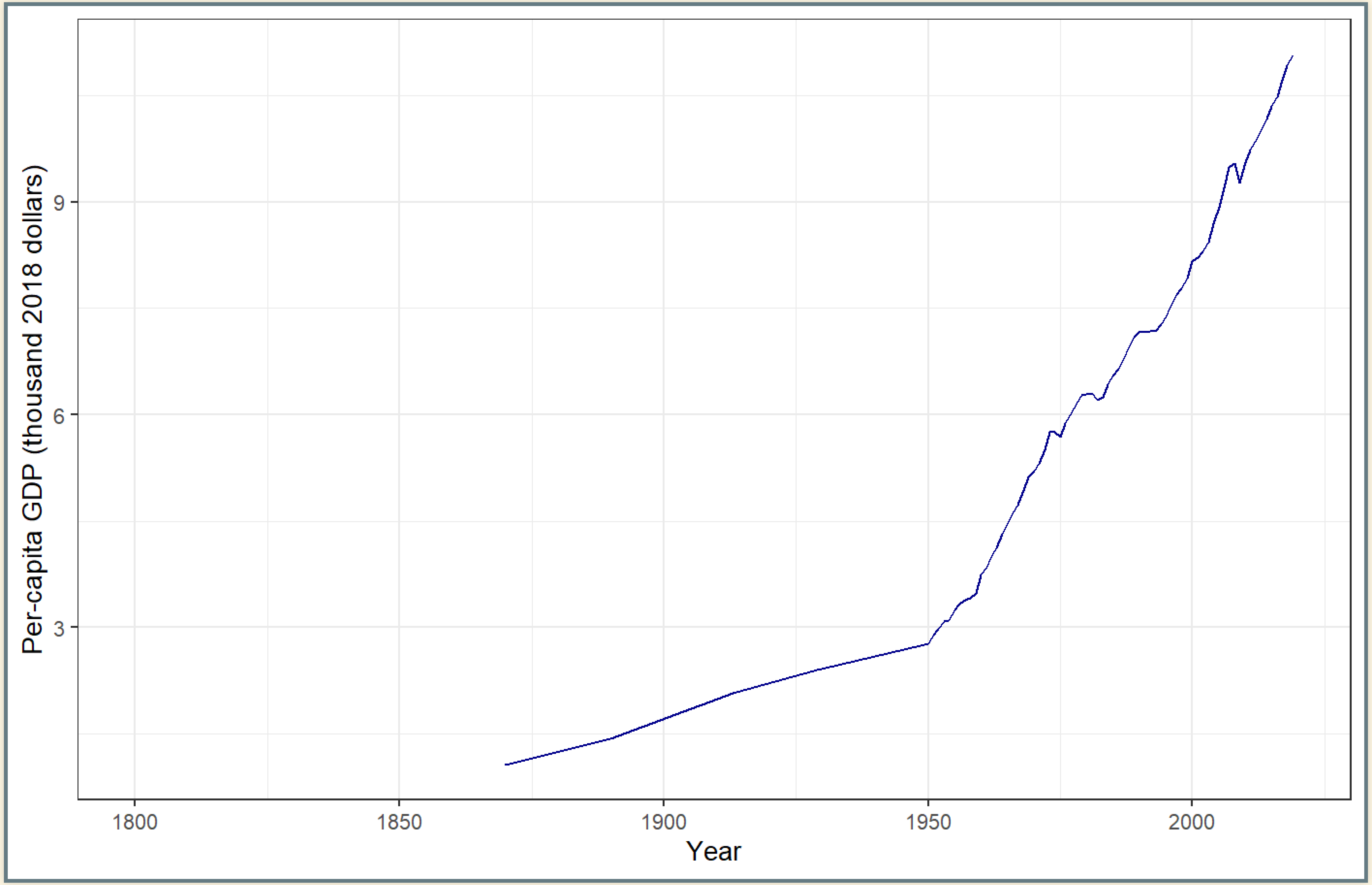
An experimental version of the interactive tool is available at https://github.com/jonathan-g/kayatool.

You can install it on your own computer,
but it may be a bit iffy when you run it.

Global Population (P)



Global Economy (per-capita GDP g)



Global Income Distribution

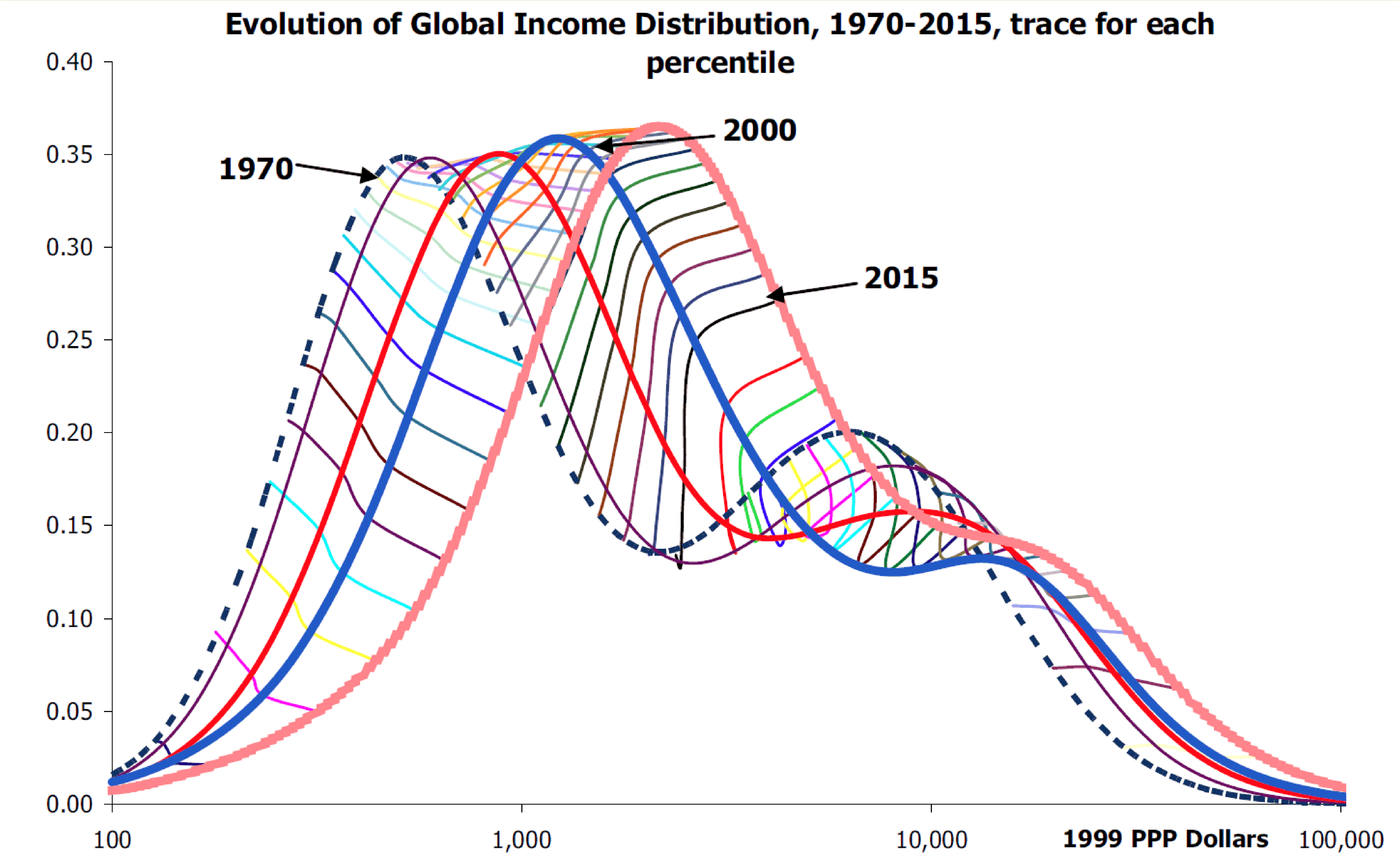


Image credit: Y. Dikhanov & M. Ward, “Evolution of the Global Distribution of Income in 1970–99” (2001).

- Big drop in “desperate poverty”
- Growth of global middle-class

Global Income Distribution

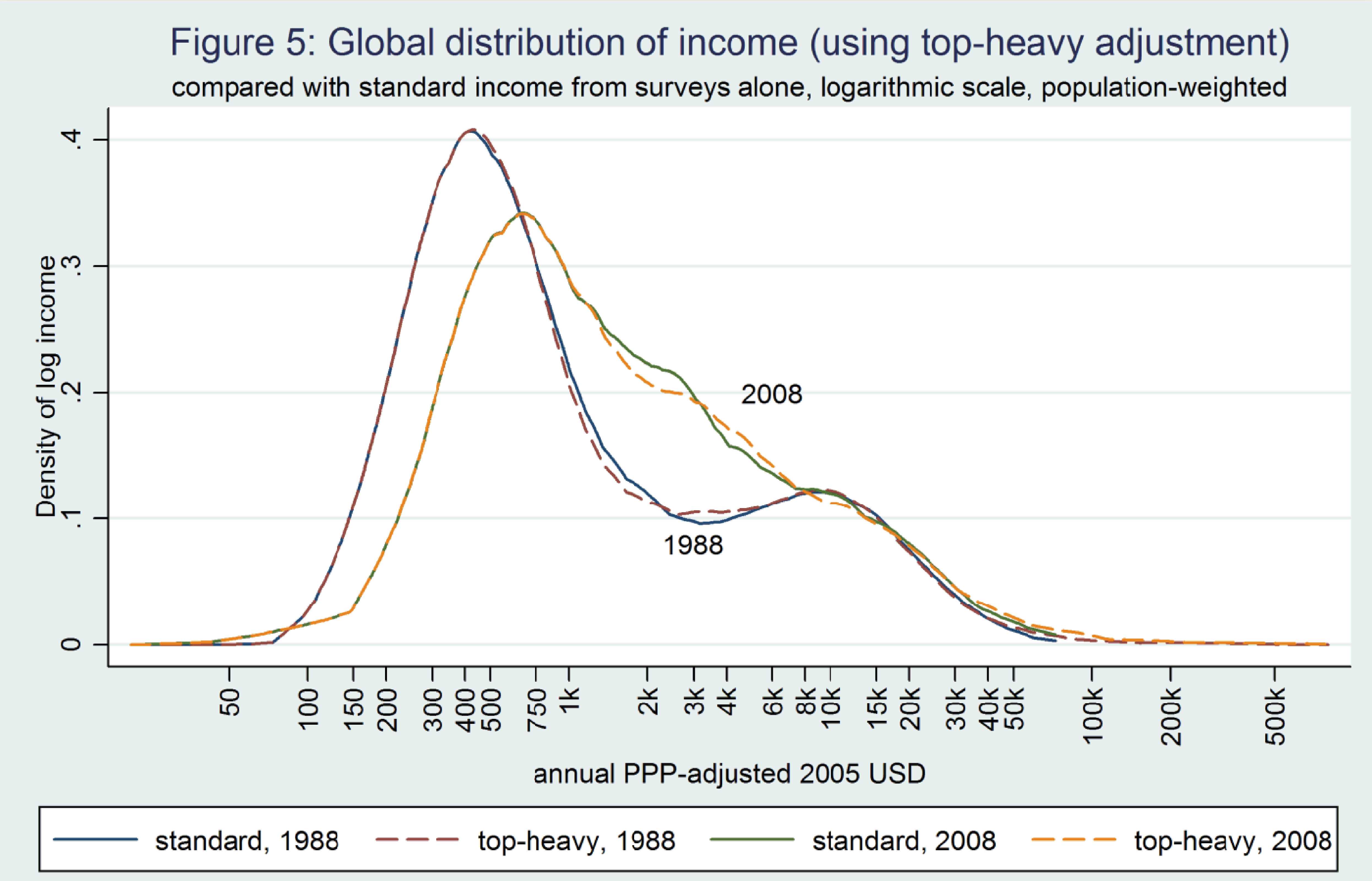


Image credit: B. Milanovic, *Global Inequality* (Harvard, 2016).

- Rightward movement of lower end: Big drop in poverty
- Growing lump in middle: Rise of global middle-class

Global Income Growth over Time

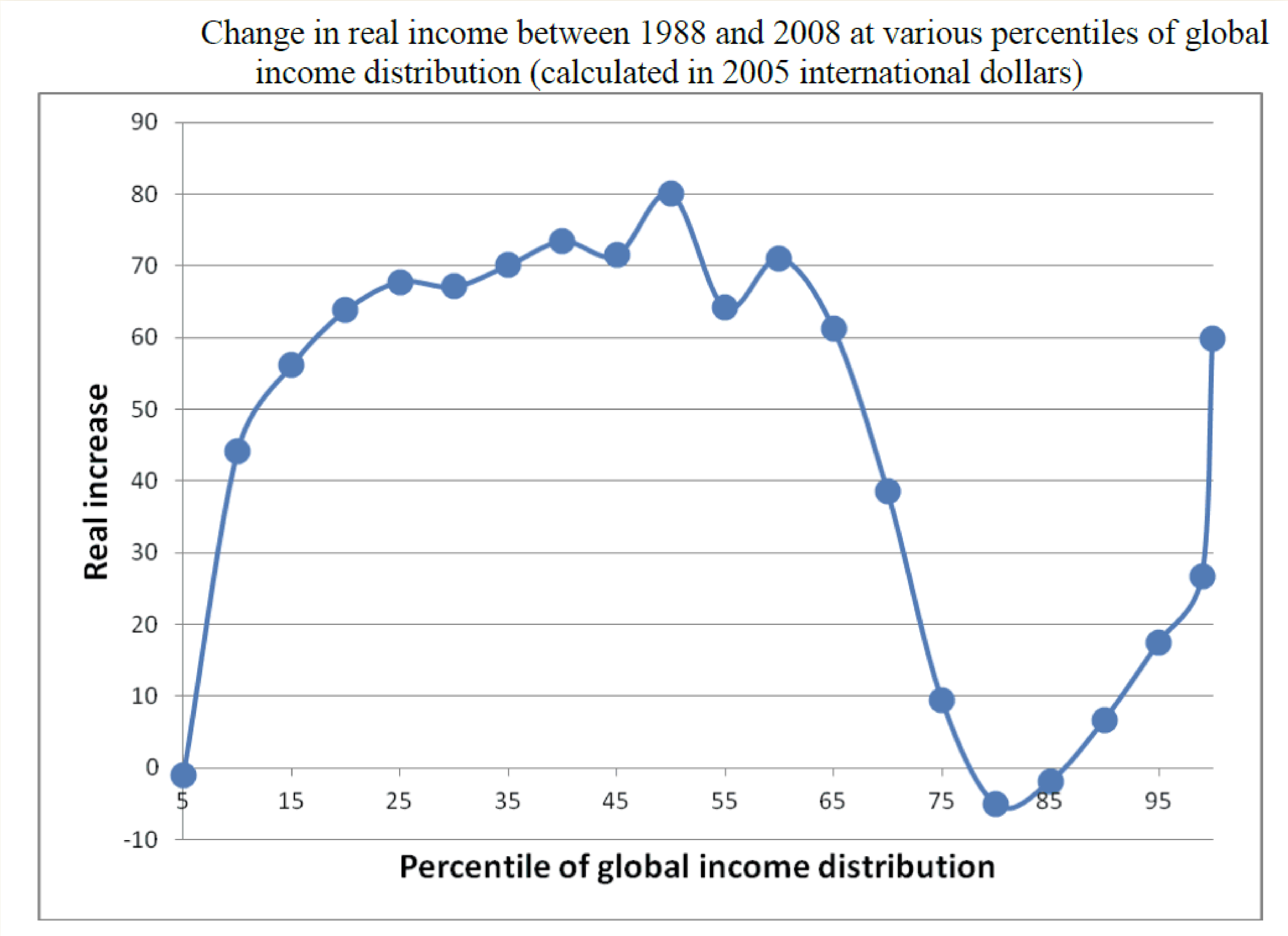
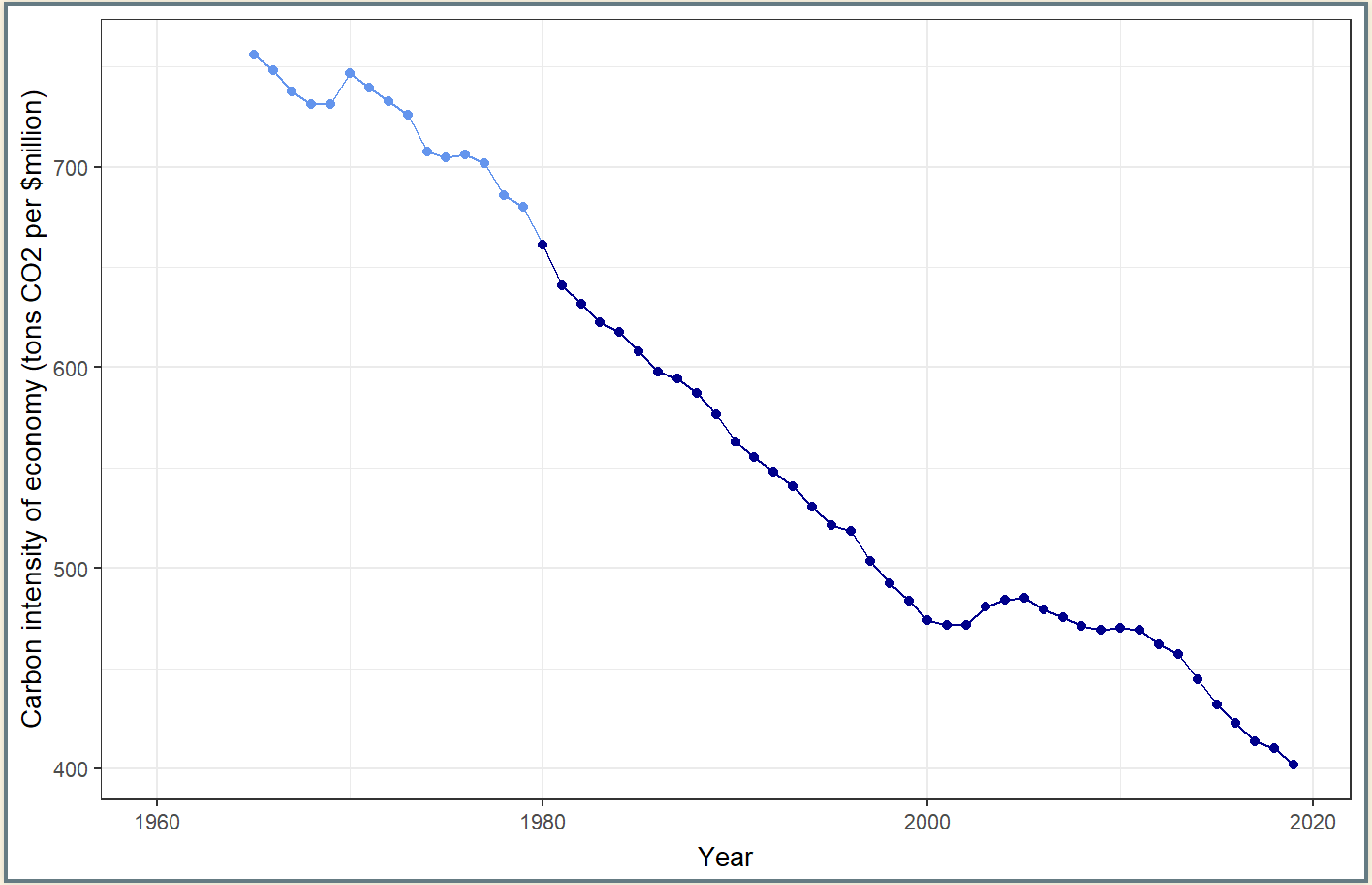


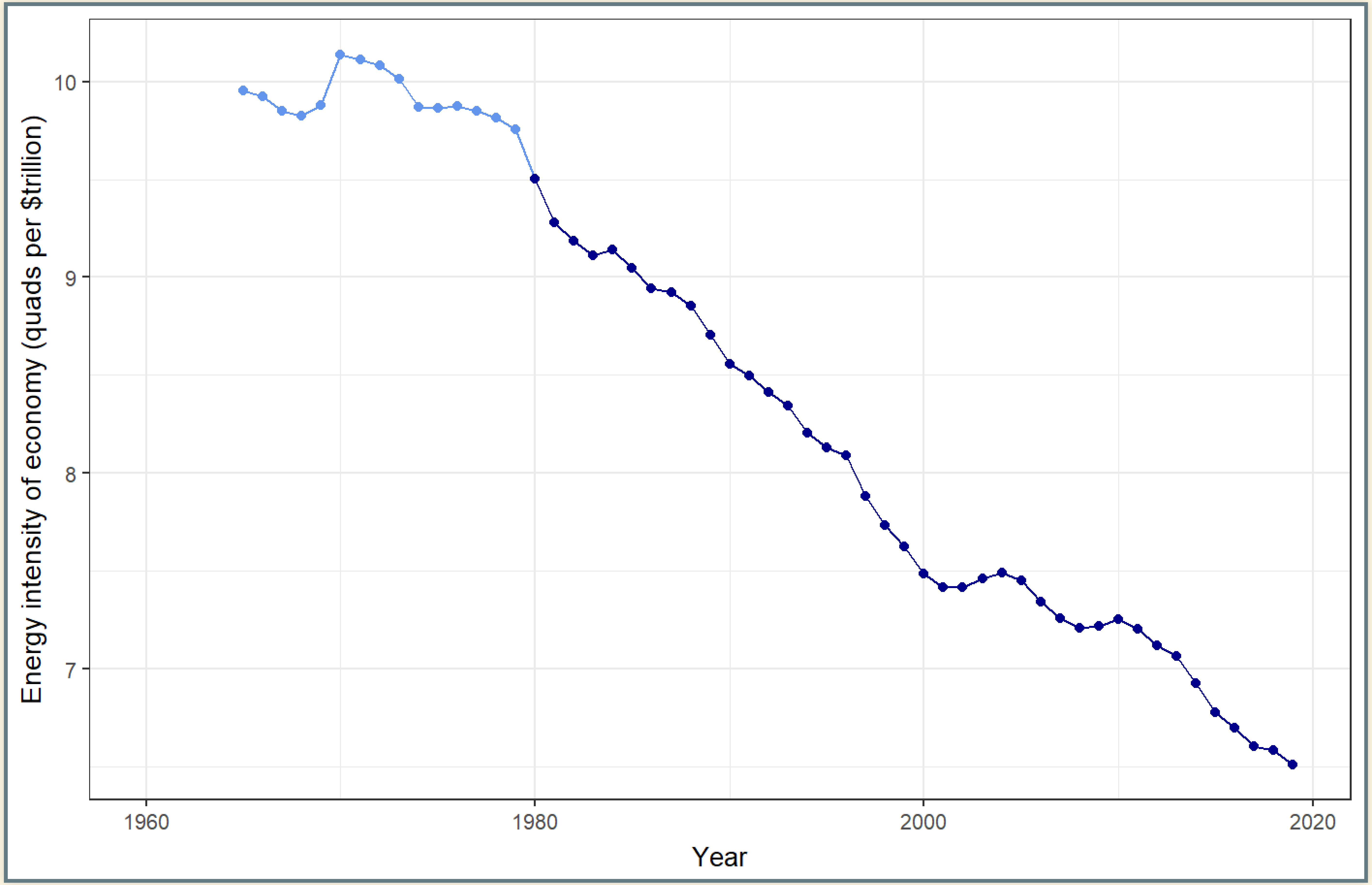
Image credit: B. Milanovic, *Global Inequality* (Harvard, 2016).

- Biggest gains for 10th–65th percentile (poor and middle class)
- Losses for 80th–85th percentile (middle class of rich nations)
- Big gains for richest 5% (> $75,000 US)

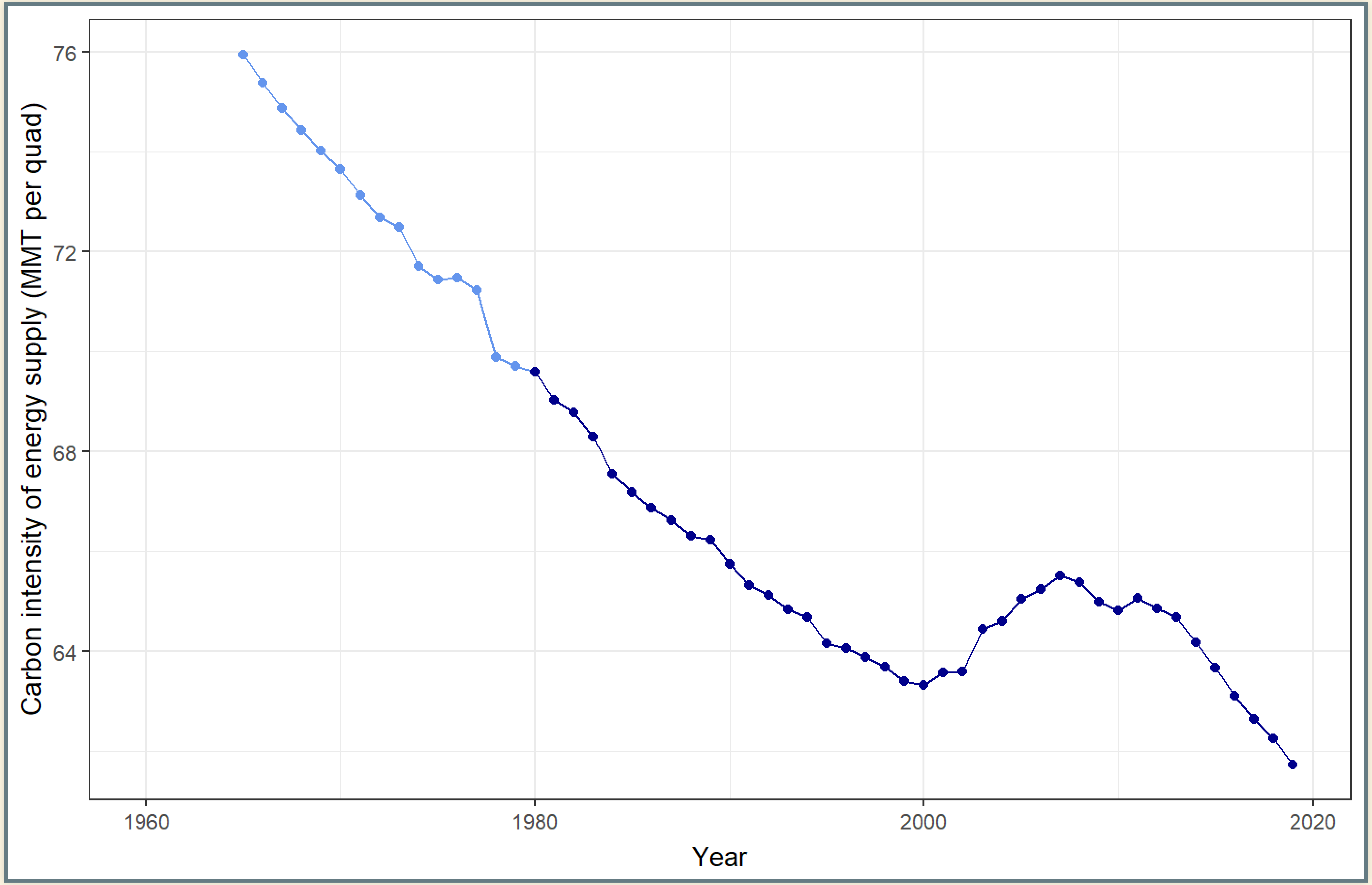
Emissions Intensity of Global Economy (*ef*)



Energy Intensity of Global Economy (*e*)



Carbon Intensity of Global Energy Supply (*f*)



Implied Decarbonization

Implied Decarbonization

- Specify emissions for 2050, compared to 2010
- Assume global GDP G grows at rate r ($5\% \rightarrow r = 0.05$)

$$\text{emissions: } F = Pgef = G \times ef$$
$$F(2050) = G(2050) \times ef(2050)$$

Growth:

$$\begin{aligned} y(\text{5 years from now}) &= y(\text{today}) \times \exp(r \times 5) \\ &\approx y(\text{today}) \times (1 + r)^5 \end{aligned}$$

- exp = exponential function (e^x).
- Call it “exp” to avoid confusing e in Kaya formula with e, base of natural logarithm.

Implied Decarbonization

- Specify emissions for 2050, compared to 2010
- Assume global GDP G grows at rate r $(5\% \rightarrow r = 0.05)$

$$\text{emissions: } F = Pgef = G \times ef$$

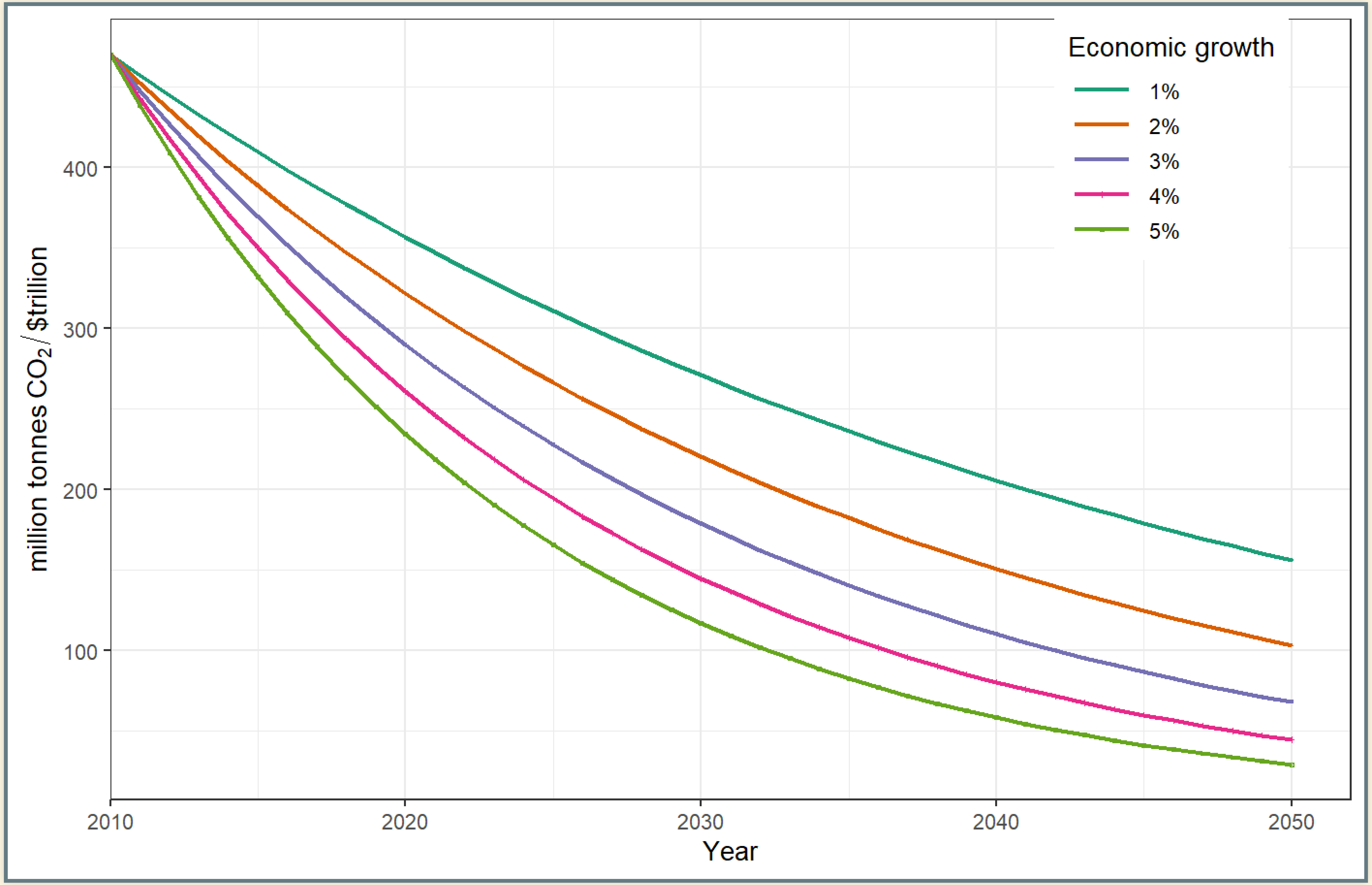
$$F(2050) = G(2050) \times ef(2050)$$

$$G(2050) = G(2010) \times \exp(r \times (2050 - 2010))$$

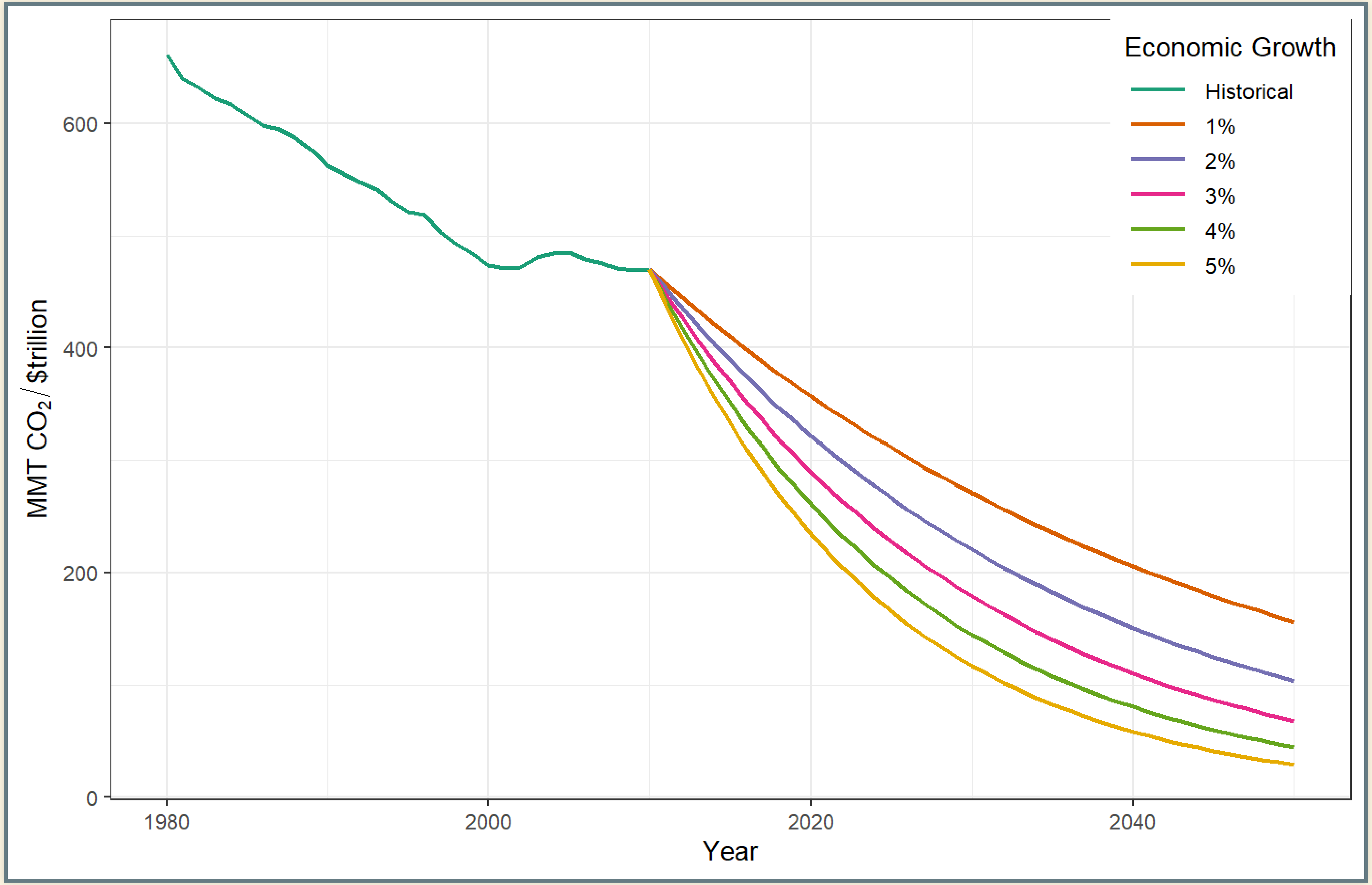
$$ef(2050) = \frac{F(2050)}{G(2050)}$$

$$= \frac{F(2050)}{G(2010) \times \exp(r \times 40)} \approx \frac{F(2050)}{G(2010) \times (1 + r)^{40}}$$

Reduce emissions 50% by 2050:



Actual and Implied Decarbonization



Pielke’s Policy Criteria

1. Policies should flow with public opinion
2. Public will not tolerate significant short-term costs, even for big long-term benefits
3. Policy must center on clean energy innovation